THE SPATIAL AND TEMPORAL DYNAMICS OF SELECTED HEAVY METALS IN THE WHITE RIVER

A SPECIAL STUDY

FINAL REPORT

PREPARED FOR

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7.2.1 Introduction

During 1982, White River Shale Oil Corporation funded an investigation in the White River, Utah to document the levels of metals related to oil shale development which might occur in the biota of the White River. The purpose of this program was to determine these levels as a baseline against which future data could be compared.

The selection of the test contaminants was dependent upon their relationship to the energy industry. Suspected compounds which may impact groundwater or surface water at the study site included: soluble salts; reduced sulphur species; soluble organics of highly variable composition; Mo; B; F; the trace metals, As, Cd, Se, Pb, Cr, Zn, Cu, Ni, Hg, Fe; and other undetermined contaminants (McWhorter 1980, Wildung and Zachara 1981). The potential impact of the industrial waste streams to surface and groundwater would depend upon the mass emissions of contaminants, various physical-chemical interactions between contaminants, the pollutant dynamics within receiving waters and the site-specific characteristics of terrestrial and aquatic environments. Based upon available information on waste stream characterization for the synthetic fuels industry, the following heavy metals were selected for this study: Cd, Cr, Cu, Pb, Ni and Zn.

Study Area: The White River, which drains approximately 10,250 km^2 flows through several distinct geomorphic regions. The drainage basin is comprised of an upper mountainous region from which a majority of the water originates and a lower, semi-arid basin through which the stream flows. This

lowland is frequented by intensive summer rainstorms which drastically alter the character of the river. As stated previously, the drainage basin has not been extensively developed, although deposits of oil shale from the Green River formation (Piceance Creek and Uinta Basins) are presently being mined. The dominant surfical deposits within the drainage basin are lacustrine sediments from Lake Uinta (Paleocene Epoch) which consist of marlstones dominated by dolomite and calcite. The water quality within the river changes markedly with distance downstream due to physio-chemical processes and ephemeral channel runoff. The White River also changes seasonally in both flow and quality with three distinct flow regimes having been observed: baseflow, lower basin runoff and upper basin runoff.

The relative concentrations of major anions/cations found in the White River, occur in the following order:

$$HCO_3^- > SO_4^= > Cl^- > CO_3^=$$

$$Ca^{2+} > Na^+ > Mg^{2+} > K^+ ,$$

This order reflects the geologic weathering and evaporation-crystallization processes taking place. In general, the highest concentrations of dissolved substances has occurred between August and March (baseflow), intermediate concentrations between April and May (lower basin) and the lowest concentrations during June and July (upper basin runoff). Data are shown in Table 7.2-1 for these runoff periods from October 1974 to September 1976. Long-term averages for the 1974 - 1980 period have indicated similar values. Suspended sediment (SS) concentrations in the river have

Table 7.2-1. The average concentrations for selected water quality parameters in the White River between October 1974 and September 1976[1].

Parameter	Baseflow (August-March)			Lower Basin Runoff (April-May)			Upper Basin Runoff (June-July)		
	n	mean	s.d.	n	mean	s.d.	n	mean	s.d.
Alkalinity($mgCaCO_3/l$)	89	199	16	27	177	58	32	134	22
Dissolved Solids(mg/l)	81	526	51	25	588	44	29	293	74
Hardness(mg/l)	89	289	31	27	301	25	32	184	39
pH(units)	64	8.1	0.4	24	8.2	0.6	28	7.8	.6
Spec. Cond.(umhos/cm)	91	813	121	27	874	71	32	473	132
Temperature(mg/l)	38	10.0	8.8	30	6.3	5.1	32	15.5	3.9
Chloride(mg/l)	88	40.0	12.0	27	41.0	6.0	32	15.5	8.5
Sulfate(mg/l)	89	176	21	27	209	20	32	88	39
DOC(mg/l)	11	6.8	3.9	6	5.8	3.4	8	5.8	1.5
Fe(µg/l)	57	28	41	19	33	21	20	38	25
Ba(ug/l)	33	48	91	14	38	38	11	27	48
Al(ug/l)	55	17	16	19	30	25	19	30	19
Mn(ug/l)	56	4	8	18	9	7	20	38	25
Cu(ug/l)	51	6.0	22	19	41	82	11	4	4
Zn(ug/l)	45	21	34	19	12	16	11	4	5
Cd(ug/l)	46	<1	1	20	1	1	11	<1	.45
Cr(ug/l)	40	2	8	14	2	5	11	<1	<1
Pb(ug/l)	46	2	2	13	4	10	11	1	1
Ni(ug/l)	46	5	5	14	2	1	11	3	2

(1) Although values may change from year to year, the data presented in this table are representative of the different flow conditions (WRSOC 1977).

shown a direct relationship with streamflow. Sediment levels and flows fluctuate widely in response to local precipitation events (Figure 7.2-1). During baseflow, SS levels averaged 100-200 mg/l whereas during upper basin runoff the levels of SS were 100-5000 mg/l (depending upon stream flow). Furthermore, SS concentrations have been recorded as high as 37,600 mg/l in the White River near Watson, Utah in response to a storm event.

Metal levels were generally within the standards for the protection of aquatic life although at times the standards were exceeded or nearly exceeded for Cu, Pb, Hg, Zn and Ag (Utah 1978). Previous studies (ERI 1981, 1982) have indicated that the White River receives natural periodic heavy metals loads associated with storm events within its watersheds which frequently result in excessive levels of dissolved metal. For example, during March 1975, a storm event increased the flow of the White River from 500 to 1100 cfs, increased SS from 200 to 2500 mg/l and dissolved copper from 4 ug/l to 340 ug/l. This phenomena has been noted for other metals, particularly Zn, Pb and Cr (Medine, unpublished data).

7.2.2 Program Summary And Recommendations

The metals study conducted in the White River adjacent to Tracts Ua and Ub has provided site-specific data for future comparisons. More importantly, this study has allowed a brief look into the mechanisms regulating the heavy metal dynamics in the White River ecosystem. While this study has not provided the definitive description of metal dynamics in the White River, it has increased our understanding to the point that pending regulations may be quantitatively addressed. The conclusions to be drawn from this study include the following:

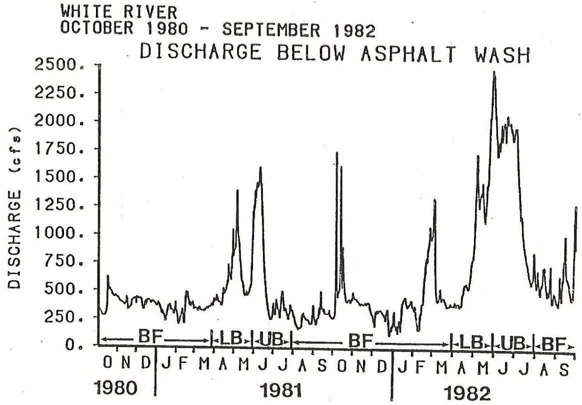


Figure 7.2-1. The discharge patterns for the White River between 1980 and 1982. BF = base flow; LF = lower basin runoff; UB = upper basin runoff.

- The metal concentrations in the ecosystem components of the White River are consistently higher than the background levels reported for uncontaminated systems.

- A major source of copper and most likely Zn into the White River are the dry washes and overland runoff.

- Spatial differences were found along transects and were correlated with the location of alluvial fans. An inspection of alluvial water quality indicated close agreement between well water quality (metal concentrations) and the elevated metal levels in the river organisms.

- Macroinvertebrates appeared to amplify the metal concentrations in the river water.

- Carbonate precipitates demonstrated the same pattern as the macroinvertebrates but appeared to provide a long-term average of river water quality.

- Although fish and sediment organics provide the same integrating capacity as the precipitates, they are extremely mobile and may not reflect site-specific conditions.

- The organisms in the White River appear to have adapted to the periodic high metal loads. They do not appear to be adversely affected by the elevated metal levels.

- Adsorption of metals by suspended sediments in the White River is a major mechanism of removal of the soluble form.

- It is believed that Chromium in the White River occurs dominantly as Cr^{+3} rather than Cr^{+6}. However, based upon concentrations in organisms adjacent to alluvial fans, alluvial water is most likely Cr VI.

- Nickel does not fit the classical adsorption pattern reported in the literature. It is believed that Ni is complexed or chelated in the river water and is prevented from interacting with solid phases.

Based upon the results of this study, ERI recommends that the major dry washes and associated alluvial fans which may be impacted by the project, be investigated for potential inputs of heavy metals and organics. This investigation should center on shallow alluvial water quality and the adjacent concentration of metals in the macroinvertebrates and precipitates. If done in a predevelopment fashion, these two ecosystem components will provide a short-term (major event) and long-term (major trend) monitoring tool which will integrate White River water quality. Because both are stationary, they also will provide an exact site-specific environmental

assessment.

It is apparent that suspended sediments play an important role in the metal dynamics of the White River. It is suggested that suspended sediment monitoring be done as frequently as possible.

Because of the behavior of Cr and Ni, and the potential for the production of organics as a by-product of the project, it is suggested that the intensive site-specific metal survey outlined above be done in conjunction with an organics survey.

During 1982, the Environmental Protection Agency (USEPA 1982) published a draft Water Quality Standards Handbook, the purpose of which was to "improve the management of the water quality standards program by ensuring that the water quality standards decision-making process is based on appropriate data and analysis, open debate among scientist peer groups, and the participation of those affected by the decision". This outlined procedure which would be carried out by the appropriate state agencies, involved an attainability policy, site-specific criteria development and the development of site-specific standards. The research reported in this report, represents a basis for providing these regulatory agencies with a new approach, for developing the methods and procedures for site-specific water quality standards.

Inherent in this new approach will be defining the site-specific criteria protocol. Herein could lie the major differences in our proposed approach compared to previous assessment efforts (USEPA 1982a, USEPA 1982b). These previous guidelines have proposed the use of various procedures; including a resident organism recalculation, indicator species, resident

species bioassay, and total versus soluble metal measurements. The approach proposed in this document incorporates several of the procedures described in the USEPA guidelines (1982) but also contains major amplifications and modifications. An outline of our suggested procedure can be seen in Figure 7.2-2. Our criteria development depends upon quantitatively establishing the critical or most sensitive ecosystem components or processes, conducting in situ subacute assays upon these specific components and supplimenting this data with laboratory experiments and published literature. As noted in Figure 7.2-2, WRSOC has already accomplished the first half of this protocol development. A load allocation would be the final output of this criteria development process which can be completed through the "model validation" previously proposed.

In order to rationally regulate the potential environmental pollutants from the project, an innovative approach to the development of water quality criteria is necessary. The criteria selection process must ensure that water quality standard decisions are based upon, (1) appropriate data which reflects local, site-specific environmental conditions in the White River, (2) ecosystem response to the target pollutants and, (3) anticipated downstream use. The approach should carefully evaluate both spatial and temporal variability, the influence of hydrologic phenomena, natural mechanisms for the attenuation of ambient pollutant levels and the allowable mass emissions within the constraints imposed by the attainable or established use. The basic hypothesis under which criteria development should proceed is that the systematic evaluation of structure, function and the physical-chemical-biological interrelationships of an aquatic ecosystem

Site Specific Water Quality
Criteria Development

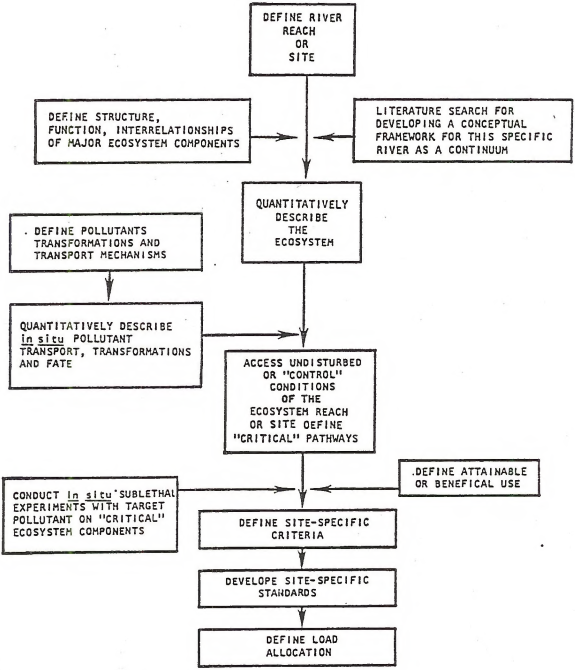


Figure 7.2-2. An information flow diagram for establishing site specific water quality criteria and load allocations.

can lead to the development of scientifically defensible, site-specific water quality criteria and tolerable mass emissions (load allocations). An attempt has been made in Figure 7.2-2 to outline the perceived necessary steps for establishing the site-specific criteria development process.

7.2.3 Program Description

7.2.3.1 Study Objectives Specific objectives of this study were:

- Define the mechanisms of transport and transformation for selected metals in the White River (pathway identification).

- Determine the ultimate fate of selected metals in the White River ecosystem (structural distribution).

- Based upon study results, provide WRSOC with recommendations relative to the existing metals levels, metal loading locations, and future regulatory requirements.

7.2.3.2 Experimental Methods Three sites were selected along the middle course of the White River for the first set of samples taken on 4-25-82 (Figure 7.2-3). A more comprehensive collection was made on 10-8-82 encompassing six sites. The upstream site for both collections was in the White River at Cowboy Canyon and represented an area of the river above major outcrops of raw shale of the Green River Formation. The intermediate site, WRSOC monitoring transect WR03 (below Evacuation Creek), was selected because of its location relative to the only perennial tributary along this section

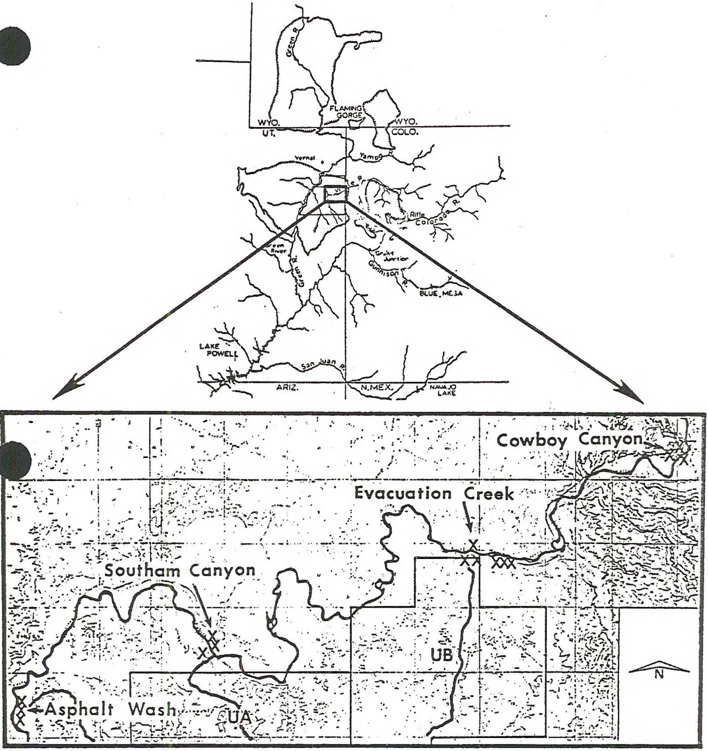


Figure 7.2-3. The location of the White River and the Federal Lease Tracts Ua-Ub. Sample sites are noted by "x".

of the White River (four miles below Cowboy Canyon) and the presence of raw shale outcrops within the river itself. The lower site sampled during the first collection was WRSOC monitoring transect WR18 at Southam Canyon, 10 miles downstream from the Evacuation Creek site. This site was adjacent to the Federal Lease Tracts Ua and Ub. The second collection included all of the above sites and the addition of a collection site immediately above Evacuation Creek, as well as sites above and below Asphalt Wash which was approximately 5.0 miles below the Southam Canyon site on the White River.

A. Field Methods At each site, a rocky substrate area was selected for sample collections. Periphyton was scraped or picked from the rock substrates, placed in plastic bags, frozen and returned to the laboratory. In a similar manner, rocks which contained a white precipitate were scraped in the field, placed in a plastic bag, frozen and returned to the laboratory. Coarse detritus was collected concurrently with the macroinvertebrate samples. Substrate sediment samples were collected from the stream bottom and returned to the laboratory for drying and screening (<0.25mm). Fish were collected by seining at each site, frozen and returned to the laboratory for processing.

B. Laboratory Methods Periphyton, precipitates, sediments, macroinvertebrates, detritus and fish were separated, air dried, dissected if necessary and homogenized. The solid samples were then freeze-dried prior to preparation for digestion. Dried samples were weighed to the nearest 0.01 mg prior to digestion with the total weight for most samples between 0.500 and 1,000 g. Samples which were less than 0.500 g were digested in a micro-digestion apparatus which used smaller digestion tubes (approximately

10 ml) and proportionally reduced reagent volumes.

All glassware was thoroughly washed and soaked overnight in 1:1 HCl and rinsed with reagent grade water (Millipore Milli-Q System). Hot 1:1 nitric acid was added to each piece for an additional 24-hour soaking. Final preparation included three rinses with reagent grade water and one additional soak with 1:4 HNO_3 (ultra-pure) and three final rinses with reagent grade water. Results indicated very little contamination from reagents and processing of the samples. The digestion procedure involved a nitric acid and hydrogen peroxide digestion of the samples in a Tecam block digestor programmed for at least 8 hours of digestion at 150°C. Dried samples were placed in 75 ml digestion tubes, followed by 5.0 ml of HNO_3. Digestion was carried out for several hours after which 2.0 ml of H_2O_2 was added to each tube. Blanks were carried through the entire process for subtraction of metal mass in reagents and water used in the process. Solid samples from the National Bureau of Standards and aqueous metal samples from the EPA were used to evaluate recovery (95-100%) and to establish appropriate instrumental parameters. After digestion, samples were filtered (if necessary) and brought up to a defined volume (75 ml-macro; 10 ml-micro).

The analysis of sample extracts was carried out using an Instrumentation Laboratory Model IL-551 Atomic Absorption Spectrophotometer equipped with a Model IL-555 graphite furnace and a Model IL-254 Fastac Autosampler. Relative standard deviations (n=3) for all standards were kept below 2.0% and were generally 1.0% or less. Samples were analyzed in the linear range or diluted to respond to the linear range of the instrument. A minimum of five standards were used to generate standard curves. Additional analyses were

conducted on the precipitates for Al, Fe, Ba, Mn, Ca and Mg by an Instrumentation Laboratory Model IL-200 Inductively Coupled Argon Plasma Spectrometer.

7.2.4 Program Results and Analysis

As noted in the previous section, two separate collections for metals were made at selected sites along the White River during 1982. These two time periods represented different hydrological conditions within the river system. The first sample period (4-25-82) represented a period of time where flow conditions were low and TDS levels high (Table 7.2-2). The biological community reflected these conditions with high biomass levels. However, the second set of samples was taken after spring runoff in an unusually wet summer with frequent storm events (Figure 7.2-1). Flow was substantially higher and TDS levels lower. The biomass levels at the same sites were also reduced substantially.

7.2.4.1 Structural Distribution A comparison of the metal concentrations in the various components of the White River ecosystem for the two dates can be seen in Table 7.2-3. These values represent the mean concentrations for a sample date, regardless of site location. In general, Cd, Cr and Ni were reduced in concentration for all ecosystem components between the two samples dates, whereas Zn, Cu and Pb decreased in only one-half of the compartments.

During the 4-25-82 sample period, the following sequence was observed for the metal concentrations in the ecosystem (highest to lowest):

macroinvertebrates>coarse detritus>fine detritus>algae>fish>precipitates

Table 7.2-2. A comparison of physical, chemical and biological structural parameters in the White River at two representative riffle transects during the two sample periods.

Parameter	Location	Date	N	Mean±S.E.	Min	Max
Fine Detritus (%)	WR03(1)	4/82	6	1.02 ± .06		
		10/82	5	.57 ± .10		
	WR18(2)	4/82	5	1.06 ± .08		
		10/82	5	.76 ± .20		
Coarse Detritus (g/m^2)	WR03	4/82	6	51.8 ± 17.8		
		10/82	5	10.5 ± 3.1		
	WR18	4/82	9	97.4 ± 46.1		
		10/82	5	17.6 ± 5.4		
Algae (mg Chl a/m^2)	WR03	4/82	5	61.8 ± 21.6		
		10/82	3	36.8 ± 6.9		
	WR18	4/82	5	43.0 ± 14.5		
		10/82	5	24.4 ± 15.3		
Macroinvertebrates(#'s/m^2)	WR03	4/82	6	135 ± 71		
		10/82	5	80 ± 80		
	WR18	4/82	8	71 ± 25		
		10/82	5	120 ± 28		
Macroinvertebrates(mg/m^2)	WR03	4/82	6	50 ± 31		
		10/82	5	4 ± 4		
	WR18	4/82	8	72 ± 33		
		10/82	5	34 ± 15		
Organic Drift (g/hr)	WR18	4/82	3	73.7 ± 13.7		
		10/82	2	159.8 ± 25.9		
Flow (cfs)	WR27(3)	4/81 to 4/82	28	477 ± 61	176	1489
		5/82 to 10/82	14	1183 ± 171	454	2050
TDS (mg/l)	WR27	4/81 to 4/82	19	465 ± 18	336	562
		5/82 to 10/82	22	303 ± 22	159	467
Conductivity (umhos/cm)	WR27	4/81 to 4/82	26	736 ± 31	578	898
		5/82 to 10/82	21	499 ± 234	234	659
pH (units)	WR27	4/81 to 4/82	30	8.19 ± .05	7.40	8.70
		5/82 to 10/82	22	7.95 ± .06	7.38	8.68

(1) WR03 = Evacuation Creek Site

(2) WR18 = Southam Canyon Site

(3) WR27 = Asphalt Wash Site

Table 7.2-3. A summary of all metals data collected in the White River by date during the special study.

Compartment	Date	No.	Metal Concentrations ($\bar{x}$ ± S.E.; ug/g D.W.) Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Water (ug/l)			.136 ± .074	3.14 ± .95	2.65 ± .46	.64 ± .26	3.47 ± .79	14.0 ± 4.9
	4-25-82	(6)	.58 ± .16	38.5 ± 7.4	16.9 ± 1.5	10.3 ± 1.57	19.9 ± 2.5	23.9 ± 2.9
Precipitate ($CaCO_3$)	10-8-82	(12)	.43 ± .03	31.7 ± 3.7	12.4 ± .41	12.7 ± .61	8.28 ± 1.06	30.67 ± 2.71
Fine Detritus-Sediments	4-25-82	(3)	1.05 ± .12	67.5 ± 7.0	19.2 ± .58	35.6 ± 2.27	24.8 ± .96	78.1 ± 3.2
Coarse Detritus	4-25-82	(2)	2.48 ± .67	29.1 ± 15.5	122.1 ± 102.0	17.6 ± 12.7	24.7 ± 19.4	206.0 ± 37.0
	10-8-82	(21)	.80 ± .04	14.3 ± .88	51.4 ± 3.9	17.9 ± .5	8.81 ± .47	70.0 ± 3.1
Algae	4-25-82	(4)	1.29 ± .12	58.6 ± 8.0	14.6 ± 4.9	22.4 ± 1.8	23.9 ± 4.3	83.2 ± 24.1
	10-8-82	(14)	.47 ± .06	43.4 ± 2.8	27.2 ± 4.7	45.5 ± 11.5	14.4 ± 1.3	50.0 ± 4.3
Macroinvertebrates								
Predators	4-25-82	(2)	14.3 ± 8.6	85.4 ± 54.0	56.4 ± 17.0	28.8 ± 16.0	37.8 ± 23.0	219.0 ± 20.0
	10-8-82	(3)	2.33 ± 1.04	12.9 ± 7.63	80.7 ± 52.1	9.99 ± 4.78	3.42 ± 2.26	623.0 ± 447.0
Omnivores	4-25-82	(1)	1.61	60.5	43.4	8.8	35.1	226.0
	10-8-82	(14)	2.11 ± .64	7.44 ± 1.18	85.1 ± 29.9	10.9 ± 2.49	4.25 ± .94	437.0 ± 203.0
Total Macroinvertebrates	4-25-82	(6)	12.9 ± 6.5	72.5 ± 23.4	92.1 ± 25.5	20.4 ± 6.8	47.5 ± 14.8	275.0 ± 31.3
	10-8-82	(17)	2.15 ± .55	7.85 ± 1.36	84.3 ± 25.7	10.71 ± 2.16	4.11 ± .85	469.0 ± 180.0
Fish								
Flannelmouth	4-25-82	(2)	1.67 ± .05	13.89 ± 6.8	12.4 ± .09	3.63 ± .15	6.01 ± 2.5	118.1 ± 13.4
	10-8-82	(4)	.26 ± .03	2.02 ± .44	40.1 ± 7.1	1.11 ± .18	.79 ± .14	74.0 ± 3.1
Chubs	4-25-82	(5)	2.35 ± .94	8.08 ± 3.3	26.6 ± 15.2	2.35 ± .71	3.93 ± .89	265.0 ± 43.0
	10-8-82	(3)	.21 ± .05	2.23 ± .96	32.2 ± 1.9	1.16 ± .21	.25 ± .06	126.0 ± 12.8
Blueheads	4-25-82	(2)	1.07 ± .22	5.17 ± .80	16.4 ± 1.3	2.52 ± .01	2.52 ± .24	73.5 ± 1.4
	1-8-82	(2)	.14 ± .02	7.06 ± 1.8	33.2 ± 7.8	2.34 ± .48	1.35 ± .55	81.3 ± 7.6
Speckled Dace	4-25-82	(1)	0.93	1.26	10.2	0.79	1.96	218.0
	10-8-82	(4)	.36 ± .04	1.36 ± .42	20.1 ± 3.4	.79 ± .12	.34 ± .13	135.0 ± 14.0
Total Fish	4-25-82	(11)	1.94 ± .45	7.79 ± 2.20	18.6 ± 6.9	2.44 ± .38	4.98 ± 1.33	193.0 ± 31.0
	10-8-82	(14)	.26 ± .03	2.65 ± .59	30.4 ± 3.1	1.45 ± .28	.68 ± .14	110.5 ± 9.7

This sequence changed during the 10-8-82 sample period with the following order being noted:

coarse detritus>algae>macroinvertebrates>precipitates>fish

Although these are general sequences and tend to vary from metal to metal, the organic phases (detritus, algae or macroinvertebrates) were always higher in concentration when compared to fish or $CaCO_3$ precipitates.

A spatial comparison of the metal levels by trophic groups (Table 7.2-4; Figures 7.2-4 and 7.2-5) indicated that the abiotic compartments (carbonate precipitate and the fine detritus sediment fraction) increased with distance downstream but did not demonstrate wide variability. A similar pattern was found for the fish. A comparison between dates for the precipitates and fish indicated that their respective metal sequences (highest to lowest concentration) were the same for both sample dates (Figures 7.2-4 and 7.2-6). It is interesting to note that the Cr, Ni, Cu and Cd metal concentrations in the precipitated carbonates were reduced in the river just below Evacuation Creek (site WR03) during the second sample period. A detailed analysis was undertaken to better define the composition of these precipitated materials. A preliminary analysis can be seen in Table 7.2-5 for four of the sites sampled on 10-5-82. A comparison of calcium carbonate concentrations in the precipitates from above and below Evacuation Creek indicated that the calcium component of the precipitate increased downstream from the Evacuation Creek site (14.2 to 44.3 mg Ca^{++}/gm precipitate).

Table 7.2-4. The temporal and spatial concentration of metals in various trophic categories of the White River.

COWBOY CANYON

		Metal Concentration (ug/g dry weight; $\bar{x} \pm$ S.E.)					
	Date	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Precipitata	4-25-82	0.17 ± .07	40.9 ± 11.9	12.9 ± 1.03	5.71 ± 0.15	24.6 ± 3.5	26.2 ± 2.5
	10-8-82	0.42	33.8	11.4	6.16	11.5	27.9
Algae	4-25-82	0.32	9.5	8.1	10.8	4.9	29.0
	10-8-82	1.09	40.6	19.7	10.4	27.9	34.6
Fina Detritus	4-25-82	0.82	62.2	19.8	36.2	25.8	77.2
	10-8-82	--	--	--	--	--	--
Coarse Detritus	4-25-82	--	--	--	--	--	--
	10-8-82	0.56	11.8	26.2	6.58	14.4	44.5
Macroinvertebratas(all spacias)	4-25-82	50.7	14.8	49.3	1.38	49.0	172.0
	10-8-82	0.59	1.29	0.94	0.21	0.79	19.3
Fish (all species)	4-25-82	1.51 ± .20	4.35 ± 0.5	9.9 ± .7	1.99 ± 0.23	5.11 ± 1.35	154.0 ± 17.5
	10-8-82	0.23 ± .01	1.52 ± 0.2	34.6 ± 1.6	0.61 ± 0.9	0.98 ± .08	99.6 ± 10.6

BELOW EVACUATION CREEK

		Metal Concentration (ug/g dry weight; $\bar{x} \pm$ S.E.)					
	Data	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Procipitata	4-25-82	0.99 ± 0.1	43.5 ± 10.4	17.8 ± 0.3	11.9 ± 1.0	20.2 ± 0.4	29.2 ± 0.4
	10-8-82	0.34	10.4	5.32	5.36	8.20	28.7
Algae	4-25-82	1.05	46.2	17.4	27.0	17.9	54.1
	10-8-82	0.34 ± .11	53.9 ± 3.8	30.2 ± 10.7	18.5 ± 1.6	43.2 ± 12.8	66.9 ± 6.9
Fine Detritus	4-25-82	1.11	58.9	18.0	31.4	22.7	73.1
	10-8-82	--	--	--	--	--	--
Coarsa Datritus	4-25-82	1.80	44.6	203.0	30.2	44.2	243.0
	10-8-82	0.75 ± .10	21.1 ± 6.7	57.3 ± 11.5	20.2 ± 4.0	7.58 ± .47	66.7 ± 5.5
Macroinvertabrates(all spacias)	4-25-82	39.1	117.0	79.2	19.9	103.0	254.0
	10-8-82	0.76 ± .08	4.58 ± 1.12	14.9 ± 1.90	2.08 ± .99	2.01 ± 1.06	208.0 ± 17.0
Fish (all spacias)	4-25-82	1.54 ± .15	5.17 ± 0.44	13.8 ± 1.29	1.75 ± .21	3.13 ± .62	186.0 ± 33.0
	10-8-82	0.21 ± 0.6	5.02 ± 2.70	30.3 ± 6.4	1.89 ± .60	0.94 ± .51	110.0 ± 29.0

SOUTHAM CANYON

		Matal Concentration (ug/g dry weight; $\bar{x} \pm$ S.E.)					
	Data	Cadmium	Chromium	Copper	Lead	Nickel	Zinc
Precipitate	4-25-82	0.58 ± .01	31.0 ± .01	20.1 ± 1.5	13.5 ± 0.2	18.7 ± .01	25.7 ± 4.9
	10-8-82	0.44 ± .06	25.2 ± 1.5	13.6 ± 1.5	7.27 ± .54	12.0 ± .15	23.0 ± 1.5
Algao	4-25-82	1.42	49.9	12.6	21.0	17.4	50.8
	10-8-82	.72 ± .01	42.9 ± 13.4	31.9 ± 4.6	15.4 ± 8.7	52.8 ± 23.4	54.3 ± .0
Fine Datritus	4-25-82	1.22	81.6	19.7	39.2	25.8	84.2
	10-8-82	--	--	--	--	--	--
Coarse Detritus	4-25-82	3.15	13.5	41.1	4.94	5.27	169.0
	10-8-82	.79 ± .04	11.3 ± .60	53.2 ± 3.5	8.95 ± .68	17.1 ± .3	62.7 ± 5.8
Macroinvertabrates(all species)	4-25-82	9.06 ± 2.50	64.6	206.0	23.5	55.7	335.0
	10-8-82	0.52	12.5	198.0	6.73	14.1	309.0
Fish (all species)	4-25-82	3.07 ± .70	16.8 ± 2.75	37.9 ± 14.4	3.87 ± .32	6.59 ± 1.0	267.0 ± 52.0
	10-8-82	0.27 ± .04	2.12 ± .59	28.3 ± 1.8	0.50 ± .20	1.71 ± .70	123.0 ± 17.0

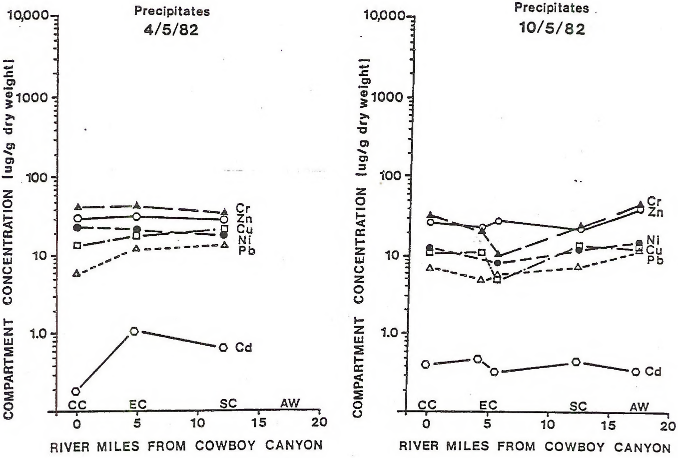


Figure 7.2-4. The distribution of metal concentrations in precipitates collected at different sites from the White River on 4/5/82 and 10/5/82.

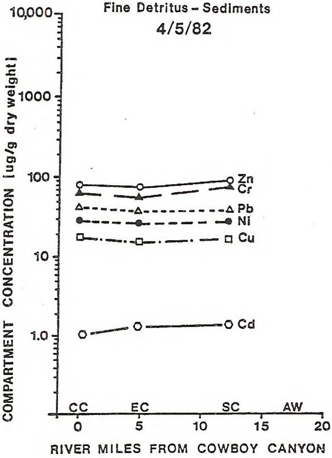


Figure 7.2-5. The distribution of metal concentrations in fine detritus from sediments collected at different sites from the White River on 4/5/82.

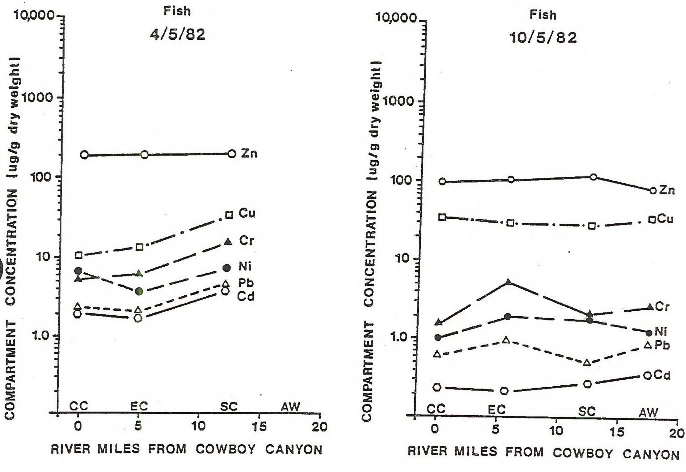


Figure 7.2-6. The distribution of metal concentrations in fish collected in the White River on 4/5/82 and 10/5/82.

Table 7.2-5. The ICP analysis of the elemental components of the precipitates collected from the White River on 10-8-82.

White River Location	Concentration (mg/g) Al	Fe	Ba	Mn	Ca	Mg
Cowboy Canyon	9.5	9.0	0.33	0.42	14.2	6.8
Above Evacuation Creek	7.2	7.0	0.23	0.36	14.3	6.9
Southam Canyon (WR18)	8.3	9.8	0.33	0.49	44.3	15.5
Asphalt Wash (WR27)	12.8	15.3	0.48	0.44	26.4	12.2

In a similar manner, the concentration of metals within the fish trophic structure was further refined to include species with different food habits as well as metal concentrations in various fish organs. A comparison between the two sample dates for the body metal loads of the fish indicated species-specific changes. During the first sample period the following sequence was observed from highest to lowest:

roundtail chub>flannelmouth sucker>bluehead sucker>speckled dace

However, during the second sample period the sequence

bluehead sucker>flannelmouth sucker>roundtail chub>speckled dace

was observed with a translocation of bluehead suckers and roundtail chubs.

The distribution of cadmium in fish organs can be seen for the study locations on 10-8-82 in Table 7.2-6. The metal concentration of various organs did display changes by sample site. For example, the concentration in skin increased steadily with distance downstream, whereas the bone, muscle and liver had a marked depression at the Evacuation Creek site. The cadmium concentration in the gastrointestinal tract corresponded well with the cadmium levels of the stomach contents for the same fish. A comparison of the mean cadmium concentrations in the organs (including all sites) indicated the following sequence of highest to lowest concentrations.

liver>kidney>gastrointestinal>fat>bone>skin>ovaries>muscle

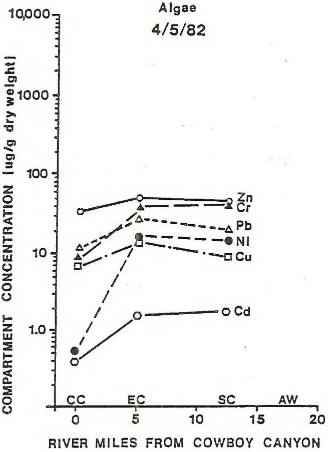
Table 7.2-6. The cadmium concentration of fish organs at selected locations in the White River, Utah. Values represent mean (±S.E.) concentrations in bluehead suckers and roundtail chubs collected on 10-8-82.

Location in The White River	Cadmium Concentration (mean±S.E.) in Organs (ug Cd/g dry weight)								
	Skin	Gastro-intestinal	Bone	Muscle	Fat	Liver	Kidney	Ovaries	Stomach Contents
Cowboy Canyon	.121±.06	.718±.268	.212±.133	.094±.021	.226	11.43	--	--	.651±.32
Evacuation Creek	.183	.805	.053	.034	--	.254	--	--	.473
Southam Canyon	.259±.116	1.43±.17	.104±.018	.081±.041	.480	10.51±10.08	--	--	3.47±2.79
Asphalt Wash	.739±.343	.857±.014	.88±.21	.043±.014	1.02±.59	5.95±4.35	5.70	0.205	.67±.58
Mean(±S.E.)	.343±.141	.973±.138	.349±.152	.067±.014	.689±.315	7.43±3.32	5.70	0.205	1.44±.81

The liver contained the highest concentrations (7.43 ug Cd/g d.w. ± 3.32) while the muscle had the lowest (.067 ug Cd/g d.w. ± .014). It appeared that analyses on whole fish for total body load for cadmium was an adequate measure of the weighted mean for all tissues. The total body load also represented a lower degree of variability similar to the muscle over distance downstream and time.

Contrary to the concentrations in the precipitates and fish, the macroinvertebrates and algae domonstrated a high degree of variability with distance downstream. For both sample dates, the concentration of all metals in the algae increased between Cowboy Canyon and the sample site below Evacuation Creek (WR03). A more detailed investigation on 10-5-82 refined the spatial distribution of the metals. These data (Figure 7.2-7) indicate that the metal content of the algae increased just downstream from the confluence of the White River with Evacuation Creek. A similar pattern was seen for coarse detritus during the second sample period in October (Figure 7.2-8).

Although the general pattern of the metal content in the macroinvertebrates was an amplification of trends observed in the other ecosystem compartments, metal levels in the macroinvertebrates sampled during the second collection decreased immediately below Evacuation Creek (Figure 7.2-9). However, below Evacuation Creek the metal concentrations in macroinvertebrates were found to be still higher than any trophic group or compartment sampled at that location.



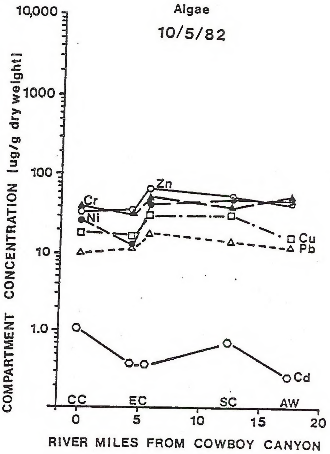


Figure 7.2-7. The distribution of metal concentrations in algae collected in the White River on 4/5/82 and 10/5/82.

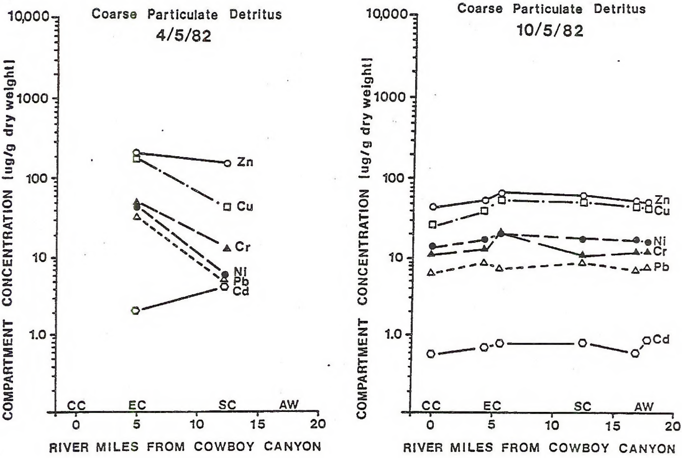


Figure 7.2-8. The distribution of metal concentrations in coarse detritus collected in the White River on 4/5/82 and 10/5/82.

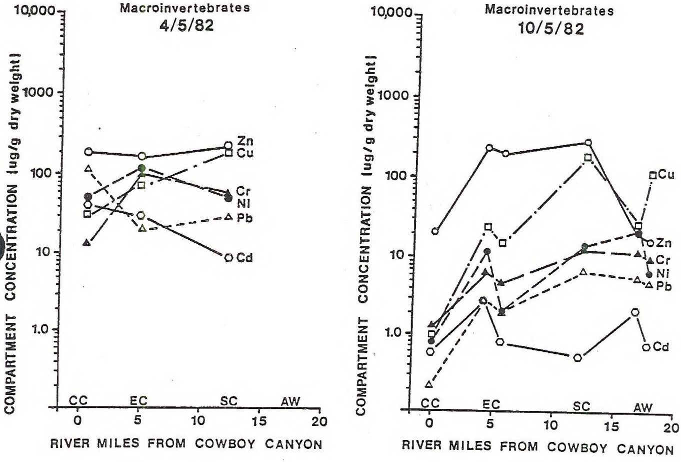


Figure 7.2-9. The distribution of metal concentrations in macroinvertebrates collected in the White River on 4/5/82 and 10/5/82.

7.2.4.2 Ecosystem Dynamics and Pathway Identification The concentrations of trace elements in most aquatic environments are usually very low (Riley and Chester 1971) although, as noted above, higher concentrations can occur in river and lake systems associated with natural and anthropogenic metal sources. These metal sources can substantially increase the heavy metal concentrations above levels normally encountered by the aquatic biota. Increases in both the essential (copper, zinc, iron and others) and nonessential (lead, cadmium, mercury, arsenic and others) metals may play an important role in regulating both the structure (Zanella 1982) and function (Medine and Porcella 1980) of the aquatic ecosystem. Furthermore, investigations of heavy metal pollution of the environment have shown that, depending on the trophic compartment studied the results can lead to different interpretations regarding the toxicity of the ambient metal concentrations. It has been suggested that, where possible, any investigation of the impacts of heavy metal enrichment on the aquatic environment simultaneously determine the metal concentrations in as many trophic levels as possible (Forstner and Whittman 1981) and determine the functional responses of the ecosystem to elevated metal concentrations (Medine et al. 1980).

As noted in the Program Description, one of the objectives of this study was to define the transport mechanisms, transformation processes and ultimate fate of metals in the White River (pathway identification).

A. Transport Mechanisms For the undisturbed White River study reach, the source locations for mass metal loadings may include; atmospheric deposition, upstream inflow, tributary or overland inflow and accrual (WRSOC

1982). Point sources may also be included for some river segments. Within the stream reach studied on the White River, the latter three processes appear to be important metal sources. Because of the annual fluctuation in flow, the water quality of the White River as an upstream source has been defined for the three major hydrologic periods (Table 7.2-1) and as annual averages (Table 7.2-7). In addition, another potential source of metals to the White River can be seen in Table 7.2-7, which represents the average water quality from the perennial Evacuation Creek and for two major ephemeral streams Southam Canyon and Asphalt Wash. The information collected in this study indicated that alluvial accrual may also represent a major source of metals to the White River system (Figure 7.2-10). Alluvial water quality from wells in each of the above major drainages has indicated high metal content in alluvial water (Table 7.2-8). It is believed that this water was entering the stream because of significantly higher metal levels in macroinvertebrates taken from the side of the river adjacent to alluvial fans compared to the non-alluvial sites (Figure 7.2-11 and Table 7.2-9). Furthermore, specific metals which were high in the alluvial water were correspondingly high in the river biocenosis adjacent to this source.

B. Metal Transformation Mechanisms It has been noted that certain physical-chemical characteristics of a water body can substantially affect the metal ion concentrations within the water and therefore, the subsequent effect of the metal upon organisms (Figure 7.2-12). Dissolved oxygen and temperature (Lloyd 1965), pH (Whitley 1968), redox potential (Reinhart and Forstner 1976), hardness (Schweiger 1956), organics-metal ion interactions (Sprague 1968), complexation (Brown and Shaw 1974), and the chemical

Table 7.2-7. The concentration of selected water quality parameters for several surface water sources to the study section of the White River. (Source WRSOC 1977).

Surface Waters

	White River (09306500)			Evacuation Creek(1) (09306430)			Southam Canyon(2) (09306610)			Asphalt Wash(2) (09306625)		
	mean±S.E.	max	min	mean±S.E.	max	min	mean±S.E.	max	min	mean±S.E.	max	min
Total Alkalinity ($mgCaCO_3/l$)	181±4	250	107	371±11.14	450	98	164±15	189	119	139±32	189	39
Dissoloved Solids (mg/l)	491±16	913	213	3290±110	4710	793	579±150	990	260	642±240	1330	305
Total Hardness (mg/l)	270±6	440	140	1040±31	1200	250	147±34	220	84	144±35	230	68
pH (units)	8.14±.04	8.8	7.2	7.93±.04	9.0	7.3	8.0±.03	8.1	7.9	7.7±.4	8.0	7.4
Conductance (umhos/cm)	751±21	1290	290	4100±113	5800	1200	789±250	1480	330	1092±350	1920	418
Sulfide (mg/l)	.148±.06	1.9	0.0	.187±.07	2.0	0.0	0			.10±.08	0.2	0
Dissolved Organic Carbon (mg/l)	5.57±0.7	9.9	2.9	14.4±2.2	35	6.2	8.50±2.5	12.0	5.0	13.0±.05	13.0	12.0
Orthophosphate (mgP/l)	.017±.03	.170	0.0	.0104±.001	.04	0.0	.083±.03	.09	.08	.08±.02	0.11	0.04
Total Phosphorus (mgP/l)	.165±.03	1.10	0.0	.0168±.003	.11	.001	7.90±2.4	14.0	1.8	23.0±12.0	40.0	5.90
Ammonia (mgN/l)	.0298±.005	.190	0.0	.0316±.004	.12	.005	.070±.010	.07	.06	.045±.03	.09	0.0
Nitrate (mgN/l)	.103±.014	.390	0.0	.546±.09	1.8	0.0	2.40±.05	2.40	2.20	2.75±.45	3.40	2.10
Nitrite (mgN/l)	.003±.001	.010	0.0	.610±.099	2.9	0.0	1.77±.25	2.40	1.40	2.47±.42	3.50	1.80
Total Nitrogen (mgN/l)	.668±.089	3.30	.10	1.59±.65	30.0	0.16	18.4±8.5	30.0	6.70	20.7±15.0	37.0	4.40
Cu (ug/l)	2.65±46	8.0	0.0	33.8±23	600	0.0	25±21.2	40	10	26.5±26	45	8
Zn (ug/l)	14.0±4.9	110	0.0	26.8±4.8	110	0.0	45±20	60	30	80±40	120	40
Cd (ug/l)	.136±.074	1.0	0.0	.08±.05	1	0.0	0			0		
Cr (ug/l)	3.14±.95	10.0	0.0	6.2±1.7	30	0.0	1.0±.7	2	0.0	0		
Pb (ug/l)	.64±.26	5.0	0.0	1.16±.2	4	0.0	0			0		
Ni (ug/l)	3.47±.79	12.0	0.0	4.84±.57	9	0.0	0			0		
Fe (ug/l)	39.4±9.3	270	0.0	56.6±13.3	470	0.0	150±62	290	10	195±70	360	40
Ba (ug/l)	63.2±24	500	0.0	59.2±15.7	300	0.0	150±31	200	100	200	200	200
Al (ug/l)	20±4.1	120	0.0	20.0±4.5	110	0.0	77±45	180	0.0	100±25	160	50
Mn (ug/l)	4.79±1.3	30	0.0	103±15.6	320	0.0	7.5±2.5	10	0.0	93±70	260	10

(1) perennial

(2) ephemeral

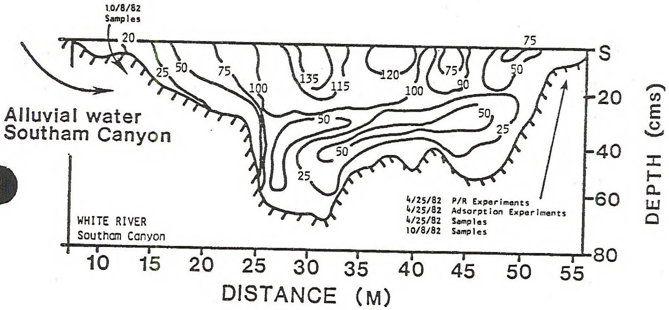


Figure 7.2-10. Cross-section profile and velocity contours (m/s) of WRSOC monitoring transect WR18. Locations of samples and experiments are shown as well as entry point of Southam Canyon alluvial water (south bank).

Table 7.2-8. The concentration of selected water quality parameters from alluvial wells in major drainages to the White River. (Source: WRSOC 1977)

Alluvial Wells

	White River (A6-1-1 upper)			Evacuation Creek (A6-8)			Southam Canyon (A6-6-2 upper)			Asphalt Wash (A6-3-3 upper)		
	mean±S.E.	max	min	mean±S.E.	max	min	mean±S.E.	max	min	mean±S.E.	max	min
Total Alkalinity(mgCaCO$_3$/l)	319±44	363	274	427±18	456	320	296±9	323	271	470±8	497	445
Dissolved Solids(mg/l)	951±29	980	921	3877±46	410	3650	3506±352	4490	2420	3340±153	3630	2680
Total Hardness(mg/l)	425±25	450	400	1171±29	1300	1100	1760±200	2300	1100	1388±105	1600	930
pH(units)	7.9±.14	8.1	7.7	7.9±.1	8.4	7.4	7.6±.1	7.8	7.4	7.8±.1	8.0	7.6
Conductance(umhos/cm)	1467±174	1750	1300	4550±230	5200	3100	4260±352	5000	3000	4132±150	4400	3490
Sulfide(mg/l)	0	0	0	0.7±.04	1.1	0.9	0	0	0	.7±.5	1.3	0.0
Dissolved Organic Carbon(mg/l)	33±5	39	27	16.6±.3	17	16	8.5±.9	11	6	23±1	25	21
Orthophosphate(mgP/l)	.005±.001	0.01	0.0	.007±.002	0.01	0.0	.020±.004	0.04	0.0	.010±.002	.02	0.0
Total Phosphorus(mgP/l)	3.11±2.79	5.90	0.31	2.87±1.32	7.40	0.21	2.89±2.24	8.70	0.46	1.11±.22	1.90	0.48
Ammonia(mgN/l)	0.54±.01	0.56	0.52	.094±.018	0.14	0.04	0.08±0.02	0.14	0.01	0.67±.01	0.74	0.54
Nitrate(mgN/l)	0.24±.01	0.26	0.22	0.13±.015	0.17	0.07	0	0	0	0.08±.02	0.22	0.01
Nitrite(mgN/l)	0.25±.01	0.27	0.23	.016±.005	0.07	0.0	0.30±.05	0.38	0.16	0.03±.01	0.16	0.0
Total Nitrogen(mgN/l)	6.1±2.5	9.8	2.4	18.5±12.1	70.0	1.5	1.67±0.60	3.30	0.63	2.60±0.5	4.6	1.1
Cu (ug/l)	3.5±.5	4	3	3.2±.6	5	1	10±3.5	18	3	4.0±1.8	11	1
Zn (ug/l)	10±1	10	10	10±4	20	0	3700±424	4600	2500	40±11	80	20
Cd (ug/l)	0	0	0	0	0	0	1.8±.8	4	0	0.4±.2	1	0
Cr (ug/l)	350±299	650	50	176±78	500	60	158±50	320	70	64±10	80	30
Pb (ug/l)	0	0	0	0	0	0	3.3±2	9	0	2.4±1.7	9	0
Ni (ug/l)	--	--	--	--	--	--	2	2	--	--	--	--
Fe (ug/l)	30±9.8	40	20	50±11.6	100	20	28±4	40	20	245±105	650	20
Ba (ug/l)	150±122	300	0	40±25	100	0	100±100	400	0	0	0	0
Al (ug/l)	25±14	40	10	24±2.2	30	20	20±4	30	10	22±6	40	0
Mn (ug/l)	425±42	470	380	780±123	1200	470	2120±168	2500	1500	410±29	460	300

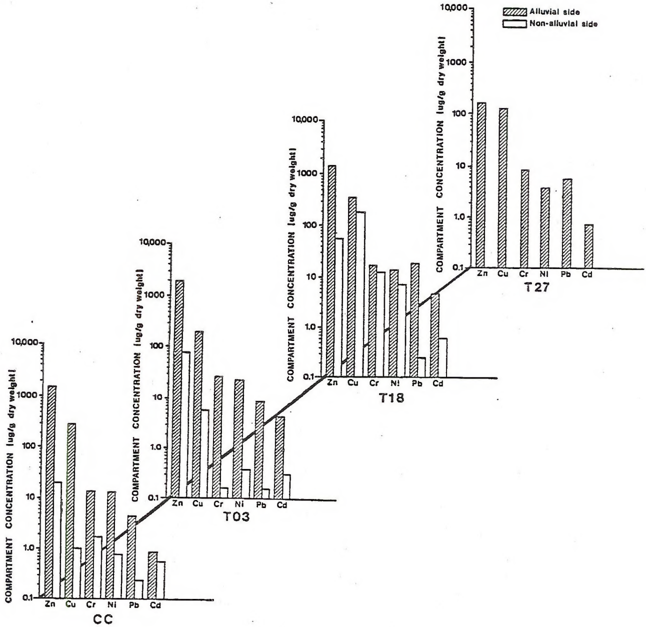


Figure 7.2-11. The concentration of metals at four sites in the White River on 10/8/82. The data compares alluvial and non-alluvial sides of the river.

Table 7.2-9. A two-way analysis of variance for metals in White River macroinvertebrates when compared between three river transects (near Cowboy Canyon, near Evacuation Creek and near Southam Canyon) and within transect locations (adjacent to alluvial fan and opposite side of alluvial fan). Data was collected on 10-8-82.

	METALS											
	Cadmium		Chromium		Copper		Lead		Nickel		Zinc	
Locations	F	P	F	P	F	P	F	P	F	P	F	P
Between Transects	1.16	0.46	0.12	0.89	4.56	0.17	21.38	0.04**	82.64	0.01**	0.6	0.62
Within Transects	13.24	0.06*	1.43	0.35	18.13	0.05*	38.44	0.02**	331.57	0.003***	8.53	0.10*

* $P \leq 0.1$
** $P \leq .05$
*** $P \leq .01$

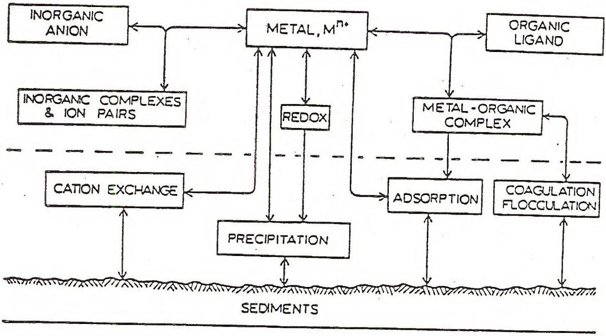


Figure 7.2-12. The natural phenomena which may affect the concentrations of heavy metals in natural environments.

characteristics of the individual metal species (Stumm and Morgan 1970) have been considered to be dominant factors in determining the effects of heavy metals on organisms. Furthermore, several studies have noted that biotic factors may play an important role in determining the response of an aquatic community to heavy metal enrichment. Factors such as the organisms' life cycles (Lovett et al 1972), seasonal variations induced by primary producers (Morris 1971), contamination of food (Flegal and Martin 1977), and the mobility of the organism (Nisimura 1974) have been shown to be important. It is believed that the observed concentrations of metals in the abiotic and biotic components of the White River ecosystem are the result of many, if not all of the above factors. A specific discussion relative to each compartment will further investigate these possible mechanisms in later sections of this report.

While data concerning actual speciation of metals in the White River are not available at the present time, previous research (Medine 1983) indicated the potential importance of $CaCO_3$ precipitation, adsorption phenomena and inorganic and organic complexation in terms of regulating soluble metals in the Colorado River and tributaries. Mass balance calculations for Lake Powell (downstream of the White River) indicated that Fe, Cu, Zn, Pb and As were 70% removed from the inflow tributaries by Lake Powell and that Se, Cr and Ni were removed to lesser degrees (40%, 15% and 8%, respectively. Calculations performed with MINEQL (Westall et al. 1976) indicated that the White and other Colorado River tributaries were supersaturated with $CaCO_3$, $Ca_5(OH)(PO_4)_3$, $ZnSiO_3$, $Fe(OH)_3$, $Ba_3(AsO_4)_2$, $Pb(OH)_2$ and $Cu_2(OH)_2CO_3$ thus implicating precipitation or coprecipitation of metals as an important

regulatory mechanism. Additional reactions (complexation, redox) may also explain why Se, Cr and Ni were removed to lesser extents than the other metals in Lake Powell. However, it appears the adsorption/desorption was a dominant mechanism controlling the transformation process and ultimate fate in this river system. It is not known whether Cr is present as a hexavalent or trivalent ion although a reasonable hypothesis based on the above results might anticipate a significant fraction of Cr occurring as Cr(VI). Cr(VI) in sediment-water systems has been removed to a lesser degree than Cr(III) as noted in previous research (Medine and Porcella 1980, Medine and Conway 1982) although significant adsorption of Cr(VI) would occur following reduction to Cr(III). The implications of metal speciation will be expanded upon in the following discussion of metal fates.

C. Metal Fate -- Inorganic Phase (Calcium Carbonate and Fine Detritus-Sediments) The coprecipitation or adsorption of trace metals with calcium carbonate has been documented in the literature (Patchineelam 1975). In the White River, the $CaCO_3$ precipitate contained substantial amounts of metals (Tables 7.2-2 and 7.2-5). Chrome was in the highest concentration of the metals studied while cadmium was the least concentrated. Experiments have been conducted on the precipitation dynamics of copper during base flow water quality conditions (Medine et al. 1984). These data (Figures 7.2-13 and 7.2-14) indicate that a direct linear relationship exists between the initial metal concentration in the aqueous phase and the amount precipitated. A further inspection of the fine detritus in inorganic sediments (which also contained $CaCO_3$ particles as well as other minerals) indicated the same pattern. The magnitude of the metal concentrations in this inorganic phase

THE SPATIAL AND TEMPORAL DYNAMICS OF SELECTED HEAVY METALS IN THE WHITE RIVER

A SPECIAL STUDY

FINAL REPORT

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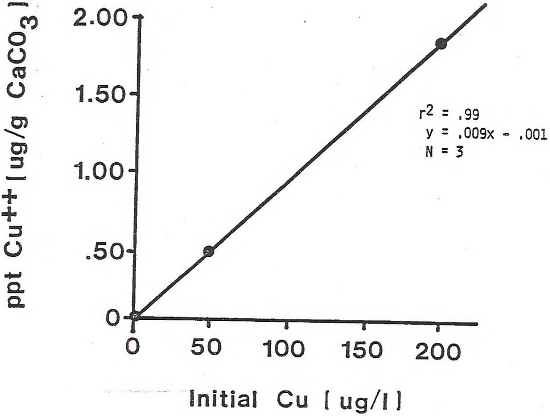

Figure 7.2-14. The relationship between the initial copper concentration and the amount of copper precipitated from White River water.

(Table 7.2-2) when compared to literature values (Table 7.2-10) indicated that chrome and nickel were in concentrations equal to or above those in contaminated systems. Cadmium and copper, although higher than naturally occurring values in other systems were not in concentrations equal to contaminated river sediments. Lead and zinc were equal to natural concentrations from other uncontaminated systems.

In Table 7.2-11, the concentration factors (water to sediments) based upon the average dissolved metal concentrations in the White River from 1949-1982 (WRSOC 1982) matched the sequence of divalent metal concentrations (Pb>Cu>Ni>Zn>Cd) found by Mitchell (1964) and Reynolds (1935). It appears that Pb, which had the highest concentration factor in the inorganic phase (precipitates and sediments), and the lowest concentration in the water, has the ability to preferentially compete for exchange sites on the sediment clays and desorb other metals such as Cd and Zn (Soong 1974). The general sequence in order of decreasing ability to exchange is Pb>Cr>Cu>Ni>Zn>Cd. This represents the same sequence observed in the concentration factors.

One of the overriding fates of metals entering the White River system appears to be the adsorption onto suspended materials and their deposition into the stream sediments. The quantitative description of heavy metal adsorption and desorption has been and is currently an area of intensive research activity. It is generally understood that descriptions of metal pathways, speciation and fates must include the role of adsorption in the regulation of metal concentrations. Heavy metal accumulation by sediments and suspended matter occurs by physical-chemical adsorption, biological uptake and by physical accumulation. The physical-chemical adsorption on

Table 7.2-10. The concentrations of Cd, Cr, Cu, Pb, Ni and Zn for various components of the aquatic ecosystem from selected studies.

Ecosystem Site	Geographical Location	Cd	Cr	Cu	Pb	Ni	Zn	Reference
		Metal Concentration ug/g dry weight						
Inorganic phases								
Sediments	Menominee River (Michigan)							
	background	0.1	10.5	10.0	143	8.2	124	Lee et al. (1982)
	contaminated	9.3	23.7	37.0	315	19.9	230	
Sediments	River Etherow(England)							
	background	2.4	9.6	10.0	54	--	74.0	Say et al. (1981)
	contaminated	23.0	99.6	72.0	200	--	4960	
Sediments	Swiss Rivers							
	background	~0.3	--	--	~50	--	~75.0	Vernet et al. (1977)
	contaminated	≤ 9	--	--	100-300	--	225-750	
Sediments	Lake Powell							
	background	2.55	19.2	--	60.0	--	12.5	Medine & Porcella (1980)
	contaminated(lab)	4.60	42.0	--	104.0	--	266	
Organic phases (periphyton)								
Cladophora	Vermillion River (Illinois)							
	background	--	--	--	14.9	46	--	Leland and McNurney (1974)
	contaminated	--	--	--	347	265	--	
Cladophora	Lake Ontario							
	background	1.4	--	6.4	12.2	--	8.2	Keeney et al. (1976)
	contaminated	3.9	--	7.2	9.5	--	23.7	
Cladophora	Leine River/FRG							
	background	0.29	--	9.1	5.2	11.9	62	Abo-Rady (1977)
	contaminated	0.94	--	23.0	49.2	23.8	190	
Organic phase (macroinvertebrates)								
Asellus	Elsenz River (F.O.R.)							
	background	0.47	--	8.64	2.69	--	119	Prosi (1977)
	contaminated	2.97	--	19.91	16.50	--	203	
Brachycentrus	Sacramento River (California)							
	background	< 2.0	--	159	--	--	92	Zanella (1982)
	contaminated	5.8	--	155	--	--	682	
Hydropsyche	Sacramento River (California)							
	background	<2.0	--	168	--	--	178	Zanella (1982)
	contaminated	5.5	--	241	--	--	1096	
Gammarus	River Werra and Weser	0.18-0.77						Zauke (1982)
Organic phase (fish)								
Blue gill	Skinface Pond (So. Carolina)	--	--	2.15	1.10	--	142	Wiener and Giesy (1979)
Warmouth	Skinface Pond (So. Carolina)	--	--	2.04	0.80	--	103	
Largemouth bass	Skinface Pond (So. Carolina)	--	--	1.88	0.50	--	75	
Redfin pickerel	Skinface Pond (So. Carolina)	--	--	2.77	1.10	--	216	
Lake chubsucker	Skinface Pond (So. Carolina)	--	--	2.64	0.40	--	79	
Shorthorn sculpin	Strathcona Sound (Northwest Territories)	1.0-1.6	--	1.6-9.9	0.1-1.2	--	28-100	Bohn and Fallis (1978)
Artic Char	Strathcona Sound(Northwest Territories)	1.6-2.3	--	1.1-4.2	0.2-0.5	--	14-33	

Table 7.2-11. The concentration factors from water into each major component of the White River ecosystem. Data collected on 4-25-82.

	Concentration Factors						
	Inorganic		Organic				
Metal	ppt	Sediments	Coarse Organics	Periphyton	Macro-invertebrates	Fish	Highest ↔ Lowest
Ni	.58	.71	.71	.69	1.36	.17	M > C ≥ S > P > P_t > F
Cr	1.20	2.10	.92	1.90	2.30	.25	M > S > P > P_t > C > F
Cd	.42	.77	1.80	.94	9.50	1.42	M > C > F > P > P_t > S
Pb	1.60	5.56	2.70	3.50	3.18	.38	S > P > M > C > P_t > F
Cu	.64	.72	4.60	.55	3.50	.70	C > M > S > F > P > P_t
Zn	.17	.56	1.50	.59	1.96	1.40	M > C > F > P > S > P_t
Highest	Pb	Pb	Cu	Pb	Cd	Cd	
	Cr	Cr	Pb	Cr	Cu	Zn	
	Cu	Cd	Cd	Cd	Pb	Cu	
	Ni	Cu	Zn	Ni	Cr	Pb	
	Cd	Ni	Cr	Zn	Zn	Cr	
Lowest	Zn	Zn	Ni	Cu	Ni	Ni	

suspended particles and the concurrent sediment accumulation or enrichment appears to be the major mechanisms by which periodic metal loads are attenuated in the White River.

The difficulty in developing quantitative models to describe adsorption/desorption in natural environments is due to the complexity of natural sediments and particulates, the effect of inorganic and organic ligands upon adsorption, the metal species distribution, and other physical-chemical attributes of the environmental system (pH, adsorbent concentration, etc). To overcome some of this difficulty, adsorption studies using "model" surfaces (clays, Al_2O_3, $Fe[OH_3]$, MnO_2) have been performed and have provided an important understanding of the mechanisms involved. A considerable amount of work has been reported on the adsorption of metals by clays (Jenne 1977, Farrah et al. 1980) although some evidence indicates that clays naturally exist as substrates coated with metal oxides or organic matter (Bourg 1982).

Additionally, work with metal oxides (Dempsey & Singer 1980, Benjamin and Leckie 1981, Elliott and Huang 1979) has resulted in considerable advances in the understanding of metal uptake mechanisms. Complexation of metal ions by inorganic and organic ligands can have a considerable impact on the adsorption by solid surfaces with the result showing an enhancement, suppression or no effect upon metal adsorption (Benjamin and Leckie 1981, Elliott and Huang 1980). Metal adsorption studies using real sediments (Brown 1979, Sholkovitz and Copeland 1981, Gardiner 1974) can provide hints about potential adsorption mechanisms and statistical correlations between particular sediment parameters and the metal mass adsorbed, but cannot give

detailed information on the operative mechanisms. It is clear that further work is necessary to quantitatively describe the adsorption process in natural systems. A series of preliminary absorption experiments were conducted in the White River with Pb, Cu and Zn (representing high and low sediment/metal concentrations, from Table 7.2-11). These suspended sediment experiments (Medine et al. 1984) were conducted in situ using reaction chambers, with natural water and sediments from the White River. The data indicated that metal removal was very rapid (<1hr.) and that increasing particulate concentration and pH were important factors in reducing equilibrium concentrations of the metal (Figures 7.2-15 and 7.2-16). Furthermore, a comparison of the concentration factors for White River sediments (Table 7.2-11) indicated that Pb would be removed to a greater extent than Zn. The results from the in situ adsorption study substantiated this conclusion (Figure 7.2-17).

D. Metal Fate-Organic Phase The passive movement of heavy metals onto detrital organics by adsorption has been investigated by Rashid (1974) and Jonasson (1977). In general, the sequence of highest to lowest concentration factors, based upon literature values are: Pb>Cu>Cd>Ni>Zn.

This sequence corresponds to the observed values from the White River (Table 7.2-11) for the coarse detritus-organic phase. The similarities in these two sequences may indicate that the concentration of metals in this organic compartment may be the result of the dissolved metal concentrations and the adsorption ability and/or complex stability of the individual metal species.

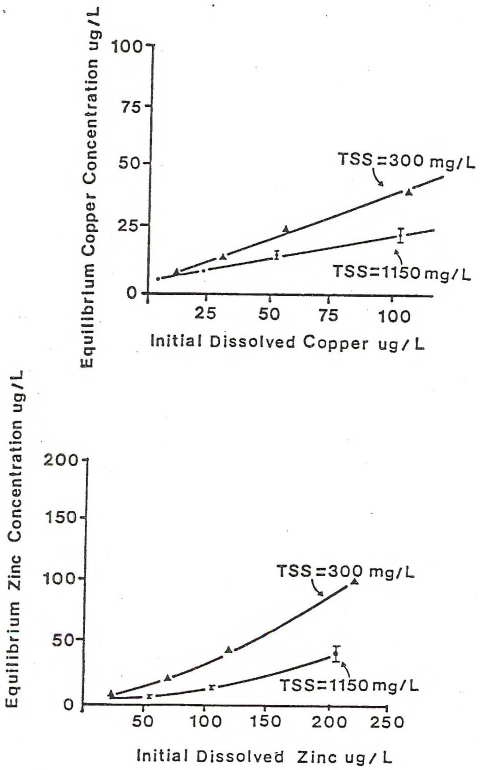

Figure 7.2-15. The effect of initial copper and suspended solids on the 24 hr equilibrium dissolved Cu (Top) and the effect of initial zinc and suspended solids on the 24 hr equilibrium dissolved Zn (Bottom) during field experiments on the White River. The reactor volume was 8 liters and temperature was maintained at ambient river temperature.

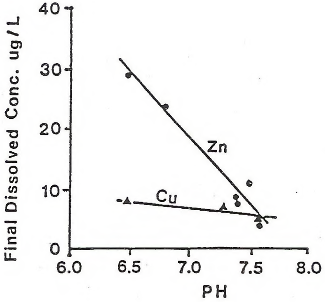

Figure 7.2-16. The effect of pH on the equilibrium level of Cu and Zn during field experiments on the White River. Desorption was highly significant for Zn. The initial levels of dissolved metal were 5 ug/l for both metals.

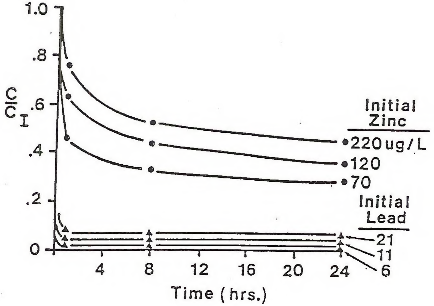

Figure 7.2-17. Adsorption vs. time for three levels of Pb and Zn during field experiments on the White River in November, 1982. Each reactor volume = 8 liters.

Aquatic organisms have a requirement for certain essential metals (Cu and Zn), while some metals (Cd, Cr, Pb and Ni) are considered nonessential. Recent studies (Davies 1973, Vancutsem and Gillet 1982, Harding and Whitton 1981) have shown that the uptake of certain heavy metals by aquatic plants was initially a passive process of adsorption onto the cell walls. The actual uptake was controlled by the rate of diffusion into the cell. The concentration of metals in the periphyton (Cladophora sp.) from the White River indicated that all the metals studied were higher than previously determined background levels from uncontaminated systems (Table 7.2-10). In several cases (Abo-Rady 1977, Kenney et al. 1976) the background concentrations in the White River were higher than contaminated sites. It should be noted, however, that Leland and McNurney (1974) reported concentrations of Ni and Pb in Cladophora sp. taken from a contaminated section of the Vermillion River that were 10 times higher than those reported in this study. The concentration factors (Table 7.2-11) for the organic phase are comparable to other literature values (Medine and Porcella 1980). As noted above, the sequence of decreasing concentration factors corresponded to the sequence of decreasing passive adsorptive abilities of the specific metals onto organic materials.

Unlike the plants which were previously discussed, there are several ways in which heavy metals can be introduced into animals. In general, there are three basic mechanisms: (1) direct uptake via skin or gills, (2) adsorption onto body tissues, and (3) from food.

It should be noted that the macroinvertebrate trophic level in this study contained a variety of organisms with different food sources.

Detritivores, herbivores, omnivores and carnivores were included. However, in each case the food types eaten by these macroinvertebrates contained significantly higher levels of metals when compared to the water. Furthermore, several of the dominant species from this trophic level were constantly in direct contact with the sediments (where elevated metal concentrations were detected). It was believed that because of these factors and the apparent lack of a homeostatic controlling mechanism (i.e. excretion), this trophic group had the highest metal concentration factor (except for Pb) relative to the water (Table 7.2-11). These results are consistent with the findings of Bryan and Hummerstone (1971). Cadmium, which had the highest concentration factor, was found to be substantially higher than reported literature values for macroinvertebrates in contaminated rivers. Zinc was found to be above background levels; whereas, Cr, Cu, Pb and Ni are comparable to other natural background values.

In comparison to literature values (Table 7.2-10), the whole body metal load in fish from the White River contained substantially higher levels of all metals when compared to other uncontaminated rivers. Experimental studies have indicated that in most cases the rates of metal uptake in fish have been related to the concentrations in the water (Pentreath 1973) and (more importantly) to the metal concentrations in the food (Hoss 1964, Renfro et al. 1974, Delisle et al. 1975). However, numerous studies have also shown that there is no certainty that the concentrations in the fish will reflect those of the environment regardless of the metal source (water or food). This is especially true for such metals as copper and zinc where excretion or some sort of regulatory mechanism has been shown to exist (Mount

1964, Brungs et al. 1973, Fromm and Stokes 1962). Non-essential metals such as Cd, Ni, Cr, and Pb are not as well regulated and can accumulate to levels 10^3 to 10^4 times the levels observed in the water (Table 7.2-11).

E. Metal Trophic Level Accumulations An attempt has been made in the previous section to quantitatively describe the transport, transformation and fate of heavy metals in the White River ecosystem adjacent to the Federal Lease Tracts Ua-Ub. There are conflicting results from studies which center around the concept of food chain enrichment with heavy metals. The results presented here appear to agree with the findings of Enk and Mathis (1977). Table 7.2-11 and Figure 7.2-18 indicate that to a certain extent, metal concentrations within the trophic structure were accumulated through the food chain, especially for non-essential metals. The major sequence in decreasing concentrations by trophic group were:

macroinvertebrates>coarse detritus>periphyton≥sediment>precipitate>fish

Although the species of metals studied exhibited food chain enrichment to various degrees, macroinvertebrates generally had the highest concentration and fish the least. The interrelationship between metal content in the surrounding environment (water, sediment, etc.) and the ability to bioregulate both essential and nonessential metals appear to be important regulating factors. Although demonstrating major differences in concentrations a strong relationship was found between the metal content in macroinvertebrates and precipitates for all metals except chromium and copper (Table 7.2-12 and Figure 7.2-19). These data indicate that the precipitates

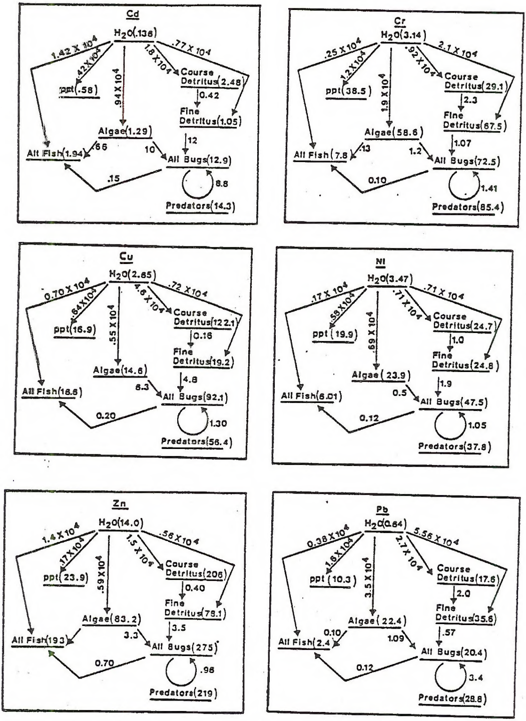

Figure 7.2-18. The trophic level accumulations for the selected heavy metals studied in the White River. Numbers in parenthesis ( ) represent ug/g d.w. While numbers by the arrows are concentration factors.

Table 7.2-12. The regression equations between the metal concentrations in precipitates and macroinvertebrates in the White River. Data collected on 4-25-82 and 10-8-82 10-8-82.

Element	Equation (y=ax+b) (1)	N	r^2	Significance Level
Lead	y = 2.57x-12.51	8	.93	.01
Cadmium	y = 62.3x-24.57	8	.94	.01
Nickel	y = 7.89x-79.60	8	.83	.01
Zinc	y = 120.3x-2870	8	.49	.05
Chromium	y = 2.69x-48.78	8	.40	NS (2)
Copper	y = 13.45x-53.38	8	.27	NS (2)

(1) y = macroinvertebrate concentration (ug/g dry weight)
x = precipitate concentration (ug/g dry weight)

(2) NS = not significant

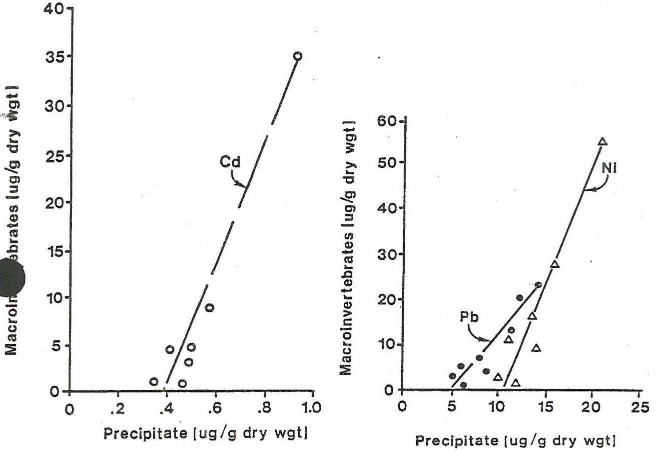

Figure 7.2-19. The relationship between macroinvertebrate metal content and precipitate metal content for all sites in the White River. Data was collected on 4-25-82 and 10-5-82.

in the White River appear to reflect long term site-specific water quality; whereas the macroinvertebrates, although having the same trends, tend to amplify the short term metal events (periodic loads).

F. Critical Pathway or Process Identification Few studies have attempted to describe the critical pathways in an ecosystem by defining the *in situ* reponse of the system to experimental pollutant loads. Gachter (1979) attempted such a study in a lake ecosystem, while Medine et al. (1980) documented a laboratory ecosystem response to heavy metal loads. Carter and Lamarra (1983) demonstrated that the use of community production and respiration rates were significant and sensitive indicators to external perturbations. Furthermore, it appeared that the *in situ* response from different systems to the same perturbation was dependent upon site-specific characteristics. A similar preliminary experiment was conducted in the White River (11-3-82 to 11-5-82) and has been reported by Medine et al. (1983). During this experiment, four chambers were used with the following treatments: (1) no additions (control), (2) EDTA ($5x10^{-7}$ M), (3) low metal additions, and (4) high metal additions. The results of the control run (first 24 hours) and the experimental run with additions can be seen in Table 7.2-13. EDTA addition and the control chamber with no additions were similar on both days. Low metal additions stimulated net production, gross production and respiration, and high metals inhibited net production and stimulated respiration. The metal concentrations (Pb, Cu and Zn) were reduced within the chambers during the 24 hours of the experiment from the initial levels (Table 7.2-14). Pb was reduced to below detectable levels

Table 7.2-13. The net production, respiration and gross production estimates from the control and treatment chambers in the White River, Utah. Experiments were conducted between 11-3-82 and 11-5-82.

Control Run (mg O_2/m^2/day				With Additions (mg O_2/m^2/day		
Net	Respiration	Gross	Treatments	Net(%)*	Respiration(%)	Gross(%)
810	317	1036	#1 No Additions	951(117%)	317 (100%)	1177(114%)
647	306	867	#2 EDTA	768(119%)	330 (109%)	1004(116%)
741	298	954	#3 Low Metal	964(130%)	304 (102%)	1181(123%)
354	165	453	#4 High Metal	311(88%)	237 (144%)	453(100%)

*% - represents the % of the control with the control being expressed as the previous days production-respiration experiment. 100% indicates that the control and treatments were equal.

Table 7.2-14. The soluble concentrations of Pb, Cu and Zn in the experimental production/respiration chambers in the White River, Utah between 11-3-82 and 11-5-82.

Soluble Metal Concentrations (ug/l)

Treatment	Pb^{+2} (ug/l)			Cu^{+2} (ug/l)			Zn^{+2} (ug/l)		
	Initial	8hrs	24hrs	Initial	8hrs	24hrs	Initial	8hrs	24hrs
No Additions	1.0	<0.5	<0.5	7.0	7.0	7.6	25.0	11.5	10.3
EDTA	1.0	<0.5	<0.5	7.0	5.6	4.6	25.0	11.0	9.6
Low Metals	6.0	<0.5	<0.5	32.0	14.0	13.0	75.0	22.0	13.2
High Metals	21.0	4.5	<0.5	107.0	30.0	36.0	225.0	54.0	30.5

within 8 hours after the start of the experiment. The results indicated that the White River ecosystem may have adapted to periodic natural metal loads it receives and that the community response can be quantified.

There are numerous examples in the literature where organisms have been shown to increase their tolerance to the toxic effects of some metals. Fish (Sinley et al. 1974), macroinvertebrates (Saliba and Ahsanullah 1973), and algae (Morris et al. 1972) have provided several examples of this possible mechanism. It has been suggested that their tolerances may be genetically determined; however, the evidence at the present time is incomplete (Bryan and Hummerstone 1973).

A second possible mechanism of adaptation may be the temporal distribution of organisms within the White River system. Zanella (1982) noted a change in species composition within the macroinvertebrate community structure over a 15 year period as a result of low level metal pollution. The two organisms described in that study were also found in the White River. The distribution of these two species over time in the White River indicated that the more resistant species an invertebrate, Hydropsyche sp. was present when water quality was potentially at its worst during base flow conditions; whereas, the less resistant species was present only during upper basin runoff when the best water quality conditions occurred.

A third possible mechanism, the adsorption and desorption of the soluble metals with suspended sediments, was investigated simultaneously with the P/R experiments (Medine et al. 1983) and have been summarized here. These data indicate that the suspended sediments within the White River can substantially and rapidly reduce the concentrations of dissolved heavy

metals. Adsorption of metals into the organic phase including algae and coarse detritus may also be an important factor in the removal of metals from solution and its concurrent increase in the phase of macroinvertebrates. The consistent levels of metals in the inorganic precipitate and sediments and fish compartments with distance downstream (Figures 7.2-4, 7.2-5 and 7.2-6) and the similarities in the sequences of adsorption ability of the metals compared to the concentration factors, may indicate that adsorption-desorption has regulated the concentration of metals in the White River between storm events.

It is important to note, that although the White River maintains a diverse and productive ecosystem, the metal concentrations present within the trophic structure are elevated above literature background levels. The exact mechanisms (genetic shifts, organism tolerance, spatial and temporal separation and the role of suspended sediments) by which this community can maintain its structure and function require further investigation.

BIBLIOGRAPHY

Abo-Rady, M.D.K. 1977. Die Belastung der oberen lieine mit Schwermetallen durch Kommumale und industrielle. Abwasser, emittelt anhand von Wasser - Sediment -, Fisch- und Pflanzenuntersuchungen. Diss Univ. Gottingen (FRG) 120 p.

Benjamin, M.M. and J. O. Leckie. 1981. Conceptual model for metal-ligand-surface interactions during adsorption. Environ. Sci. Tech. 15:1050-1057.

Bourg, A.C.M. 1982. ADSORP, a chemical equilibria computer program accounting for adsorption processes in aquatic systems. Sci. & Tech. Letters. 3:305-310.

Brown, D.W. 1979. Adsorption of lead from solution and the quartz-and-feldspar-containing silt fractions of a natural streambed sediment. IN: Jenne, E.A. (ed.) Chemical modeling in aqueous systems. ACS Syposium Series No.93. ACS, Washington D.C. pp237-260.

Brown, V.M., T.L. Shaw, and D.G. Shurber. 1974. Aspects of water quality and toxicity of copper to rainbow trout. Water Res. 8. p. 797-803.

Brungs, W.A., E.N. Leonard, and J.M. McKim. 1973. Acute and long-term accumulation of copper by the brown bullhead. Ictalurus nebulosus. J. of the Fish. Res. Bd. of Canada. 30. p. 583-586.

Bryan, G.W. and L.G. Hummerstone. 1971. Adaptation of the polychaete Nereis diversicolon to estuarine sediments containing high concentrations of zinc and cadmium. J. of the Marine Biological Ass. of the U.K. 53 p. 839-857.

Carter, J. and V. Lamarra. 1983. An ecosystem approach to environmental management. IN: Aquatic Resources Management of the Colorado River Basin. ed by V. Dean Adams and V.A. Lamarra. Ann Arbor science Ann Arbor, Michigan p260-286.

Davies, A.G. 1973. Radioactive contamination of the marine environment. p. 403-20. International Atomic Energy Agency, Vienna.

Delisle, C.E., B. Hummel, and K.G. Wheeland. 1975. Uptake of heavy metals from sediments by fish. Proc. Int. Conf. Heavy Metals Environ., Toronto. Vol. II/2, p. 821-827.

Dempsey, B.A. and T.C. Singer. 1980. The effects of cadmium on the adsorption of zinc by Mn O_x (S_n) and Fe $(OH)_{3(am)}$. IN: Baker, R.A. (ed.) Contaminants and Sediments. Vol. 2 pp 333-352. Ann Arbor Science Publishers. Ann Arbor, MI.

Elliott, H.A. and C. T. Huang. 1979. The effect of complex formation on the adsorption characteristics of heavy metals. Environ. International. 2:145-155.

Elliott, H.A. and C.T. Huang. 1980. Adsorption of some copper (II) amino acid complexes at the solid solution interface: Affect of ligand and surface hydrophobicity. Environ. Sci. & Tech. 14:87-93.

Enk, M.D. and B.J. Mathis. 1977. Distribution of cadmium and lead in a stream ecosystem. Hydrobiologia 52, p. 153-158.

ERI. 1981. Final Report: 1981 Aquatic Resources Monitoring Program. Submitted to White River Shale Oil Corporation. Salt Lake City, Utah.

ERI. 1982. Final Report: 1982 Aquatic Resources Monitoring Program. Submitted to White River Shale Oil Corporation. Salt Lake City, Utah.

Farrah, H., D. Hatton, and W.F. Pickering. 1980. The affinity of metal ions for clay surfaces. Chem. Geol. 28:55-68.

Flegal, A.R. and J.H. Martin. 1977. Contamination of biological samples by ingested sediment. Mar. Pollut. Bull. 8. p.90-92.

Forstner, U. and G.T. Whittman. 1981. Metal Pollution in the Aquatic Environment. pp. 336. Springer Verlag.

Fromm, P.O. and R.M. Stokes. 1962. Assimilation and metabolism of chromium by trout. J. of the Water Pollution Control Federation 34. p. 1151-1155.

Gachter, R. 1979. Melimex, an experimental heavy metal pollution study. Swiss Journal of Hydrology. Vol. 41 #2. p. 165-314.

Gardiner, J. 1974. The chemistry of cadmium in natural waters. II: the adsorption of cadmium on river muds and naturally occurring solids. Water Res. 8:157-164.

Harding, J.P.C. and B.A. Whitton. 1981. Accumulation of zinc, cadmium and lead by field populations of Lemnaea. Water Research. Vol. 15 p.301-319.

Hoss, D.E. 1964. Accumulation of Zn-65 by flounder of the genus Paralichthys. Trans. Amer. Fish. Soc. 93 p. 364-8.

Jenne, A. 1977. Trace elements sorption by sediment and soils: sights and processes. IN: Chapell, W. and Peterson, K. (eds.) Symposium on Molybdenum in the environment. Vol 2:425-553. M. Dekker, N. York.

Jonasson, I.R. 1977. Geochemistry of sediment/water interactions of metals, including observations on availability. IN: The Fluvial Transport of Sediment Associated Nutrients and Contaminants. IJC/PLUARG. Shear, H., Watson, A.E.P. (Eds.) Windsor, Ont. p. 255-271.

Keeney, D.R., W.G. Beck, G.W. VanLong, and J.A. Page. 1976. The determination of trace metals in Cladophora glomerata as a potential biolgical monitor. Water Res. 10, p. 981-984.

Leland, H.V., and J.M. McNurney. 1974. Lead transport in a river ecosystem. Proc. Int. Conf. Transp. Persist. Chem. Aquatic Ecosyst. Ottawa III. p. 17-23.

Lloyd, R.M. 1965. Factors that affect the tolerance of fish to heavy metals poisoning. Biol. Problems in Water Pollution, 3rd Seminar 1962. U.S. Dept Health, Education, and Welfare. 118 p.

Lovett, R.J., W.H. Gutemann, I.S. Pakkala, W.D. Youngs, D.J. Lisk, G.E. Burdick, and E.J. Harris. 1972. A survey of the total cadmium content of 406 fish from 49 New York State freshwaters. J. Fish Res. Board Can. 29. p. 1283-1290.

McWhorter, D.B. 1980. Reconnaissance study of leachate quality from raw mined oil shale-laboratory columns. U.S. EPA, Grant No. R806278. Cincinnati, Ohio.

Medine, A. 1983. Potential impacts of energy development upon water quality of Lake Powell and the upper Colorado River IN: Aquatic Resources Management of the Colorado River Ecosytem. ed by V.D. Adams and V.A. Lamarra. Ann Arbor Science, Ann Arbor, Michigan. p 397-424

Medine, A. J. and M. F. Conevay. 1982. Heavy metal interactions and dynamics in simulated Naugatuck River microcosms. Inst. of Water Resources, O.W.R.T. A-087 CONN., Storrs, Conn. 71 pp.

Medine, A., V. Lamarra, and J. Carter. 1983. The effect of suspended sediments on the heavy metal concentrations in the White River, Utah-Colorado. Unpublished manuscript.

Medine, A. and D.B. Porcella. 1980. Heavy metal effects on photosynthesis/respiration of microecosystems simulating Lake Powell, Utah/Arizona. In: Contaminants and Sediments Volume II, Edited by Robert A. Baker, Ann Arbor Science Publishers, Inc. Ann Arbor, MI. p.355-390.

Medine, A.J., D.B. Porcella, and V.Dean Adams. 1980. Heavy-metal and nutrient effects on sediment oxygen demand in three-phase aquatic microcosms. In: Microcosms in Ecological Research. Edited by John P. Giesy, Jr. U.S. Technical Information Center, U.S. Department of

Energy Symposium Series 52 (Conf - 781101). p. 279-303.

Medine, A., W.A. Lamarra, S. Bryan and S. Klein. 1984. The adsorption-desorption behavior of metals in the White River ecosystem. (Unpublished manuscript).

Mitchell, R.L. 1964. Fishes of Arizona. Published by Arizona Fish and Game. 293 pp.

Morris, A.W. 1971. Trace metal variations in sea water of the Mengi Straits caused by a bloom of Phaeocystis. Nature (London) 233, p. 427-428.

Morris, R.L., L.G. Johnson, and D.W. Ebert. 1972. Pesticides and heavy metals in the aquatic environment. Health Lab. Sci. 9, p. 145-151.

Mount, D.I. 1964. An autopsy technique for zinc-caused fish mortality. Trans. Amer. Fish. Soc. 93 p. 174-182.

Nisimura, H. 1974. Hg in fish and sediments in Tokuyama Bay. Univ. Tokyo.

Patchineelam, S.R. 1975. Untersuchungen uber die Hauptbindungsarten und die mobilisierbarkcit von Schwermetallen in fluviatilen sedimenten. Diss. Univ. Heidelberg 136 p.

Pentreath, R.J. 1973. The accumulation and retention of Zn and Mn by the plaice, Pleuronecles platessa. J. of Exp. Marine Biol. and Ecol. 12 p. 1-18.

Rashid, M.A. 1974. Adsorption of Metals on sedimentary and peat humic acids. Chem. Geol. 13, 115-123.

Reinhart, D. and U. Forstner. 1976. Metallaureicherungen in sedimentkernen aus stauhalturgen des mittleren Neckars. Neues Jahrb. Geol. Palaontol. Monatsh 5, p. 301-320.

Renfro, W.C., S.W. Fowler, M. Heyraud, and J. Larosa. 1974. Relative importance of food and water pathways in the bio-accumulation of zinc. Technical Report IAEA-163. p. 11-20. International Atomic Energy Agency, Vienna.

Reynold, A. 1935. Kationenaustausch an permutiten, insebesondere an Wasserstoff -und Schwermetall -permutiten, Kolloid- Beihefte 43, 1-142.

Riley, J.P. and R. Chester. 1971. Introduction to marine chemistry. Academic Press, New York and London.

Saliba, L.J. and M. Ahsanullah. 1973. Acclimation and tolerance of Artemia salina and Ophryotrocha labronica to copper sulfate. Marine Biology, 23. p. 297-302.

Scholkovitz, E.R., D. Copeland. 1981. The coagulation, solubility, and adsorption properties of iron, manganese, copper, nickel, cadmium, cobalt, and humic acids in a river water. Geochim. Cosmochin Acta. 45:181-189.

Schweider, G. 1956. Die toxikologische Einwirkung von Schwermetallsalzen auf Fische und Fischnahrtiere. Inaug. Diss. Naturw. Fak. Munchen.

Sinley, J.R., J.P. Goettl, and P.H. Davies. 1974. The effects of zinc on rainbow trout (Salmo gairdneri) in hard and soft water. Bull. of Env. Cont. and Tox. 12, p. 193-201.

Soong, K.L. 1974. Versuche zur adsorptiven bindung von Schwermetall-Ionen an Kunstlichen Tongemischen. Unpubl. Diss. Univ. Heidelberg.

Sprague, J. 1968. Promising anti-pollutant: Chelating agent NTA protects fish from copper and zinc. Nature (London) 220, p. 1345-1346.

Stumm, W. and J.J. Morgan. 1970. Aquatic Chemistry. New York. Wiley.

USEPA. 1982a. Water Quality Standards Handbook Draft. Office of Water Regulations and Standards Washington D.C. October.

USEPA. 1982b. Water Quality Assessment: A screening procedure for toxic and conventional pollutants - Part 1. Environmental Research Lab. Athens, 600. EPA - 600/6-82-004a 570 pp.

Utah. 1978. Wastewater disposal regulations, Part II. Standards of quality for waters of the state. State of Utah, Department of Social Services, Division of Health. 30 pp.

Van Cutsem, P., and C. Gillet. 1982. Activity Coefficients and selectivity values of Cu, Zn, and Ca ions adsorbed in the Nitella flexilis cell wall during triangular ion exchanges. J. of Exp. Bot. Vol. 33 #136, p. 847-853.

Westall, J.C., J.L. Zachary, and F.M.M. Morel. 1976. MINEQL - a computer program for the calculation of chemical equilibrium composition of aqueous systems. Technical Note 18. Dept. of Civil Eng. Mass. Inst. of Tech. Cambridge, Mass. 91 pp.

White River Shale Oil Corporation (WRSOC). 1974-1982. Water Quality Progress Reports from VTN Consultants. Salt Lake City, Utah. Unpublished data.

Whitley, L.S. 1968. The resistance of tubificid worms to three common pollutants. Hydrobiologia 32, p. 193-205.

Wildung, R. C. and Zachara, J. M. 1981. Effects of oils shale solid waste disposal on water quality: current knowledge, information, requirement and research strategy. U.S. Dept. of Energy. 27 pp.

Zanella, E.F. 1982. Shifts in caddisfly species composition in Sacramento River invertebrate communities in the presence of heavy metal contamination. Bull. Environmental Contam. Toxicol. 29, 306-312.